

Cryogenic Fluid Management (CFM) Portfolio Project

Radio Frequency Mass Gauge for Intuitive Machines (IM-1)/CLPS Program

2022 TDM Annual Review



Hans Hansen, RFMG PM; NASA Glenn Research Center
Dr. Greg Zimmerli, RFMG PI/PLE; NASA Glenn Research Center
Date: March 2, 2022

AGENDA

- Project Overview
- Technical Accomplishments in 2021
- Overview/Look Ahead for 2022
- Challenges/Risks to the Project
- Transition/Infusion Plans
- Baselined Schedules (in Backup)

RFMG FOR IM-1 OVERVIEW

Collaboration with Intuitive Machines on IM-1 through SMD's Commercial Lunar Payload Services (CLPS) Program

- ATP in January 2020, on-site access at GRC in June 2020
- Task Order 20C included RFMG integration and Cryogenic data delivery
- CFM Portfolio Project responsible for delivering EDU/Flight Antennas (LOX and LCH4) and Avionics, support HW integration into Nova-C tanks, Pre-Flight RF modeling, and support RFMG flight data analysis

Leverages previous STMD investments in RFMG

- Parabolic flights, Cryogenic Propellant Storage & Transfer (CPST) EDU Testing in 2014
- ISS demonstration on Robotic Refueling Mission 3 (RRM3) in 2018
- Scalability to large tanks during eCryo's SHIIVER Test Program in 2019/2020.

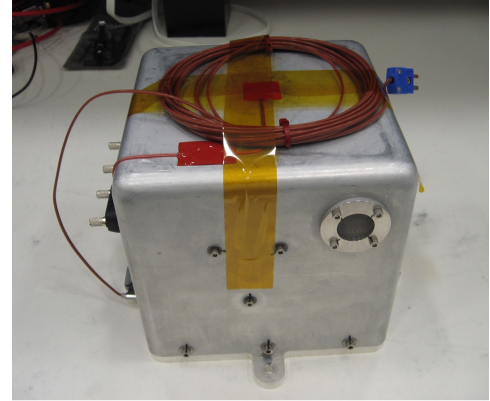


Image credit: Intuitive Machines

TECHNICAL ACCOMPLISHMENTS IN 2021

RFMG Flight Hardware/Software

- Completed assembly, Class C software verification, and environmental testing (TVAC, random vibration, EMI/EMC) of the flight avionics box
- Delivered flight avionics unit to Intuitive Machines
- Supported Intuitive Machines during installation of antennas in flight and flight-spare tanks
- Acquired RF ping test data from the flight O2 and flight CH4 tanks



RFMG Flight Avionics

RF/Fluid simulations

- Constructed RF simulation models of the tanks using CAD files provided by IM
- Migrated the RF simulation software to run on a High-Performance Computing platform
- Demonstrated good agreement between ping test data and simulated antenna responses
- Ran sample CFD simulations of propellant response to spacecraft thrust using mission specific data provided by Intuitive Machines
- Completed RF simulations of O2 tank antenna response as a function of fill level [0 to 100%, 0.5% increments]



RFMG Antenna Design

LOOK AHEAD IN 2022

Complete Pre-Flight RF and Fluid Simulations

- Compute tank/antenna response as a function of O2 and CH4 fill levels for 1g simulation database
- Develop and run a suite of CFD simulations to compute low-g fluid configurations and fluid responses to mission specific thrusts at varying tank fill levels for the O2 and CH4 tanks
- Use CFD output as input to the RF/fluid simulations
- Develop database of RF/fluid simulations to compare against measured 1g test and flight data
- Develop ability for near-real-time analysis of flight data
- Further improve the RFMG gauging algorithm software and GUI; develop to NASA Class E

Support Intuitive Machines during final Integration/Test and Flight Operations

- Conduct joint avionics & RF cabling installation with IM on EDU and flight vehicle; support testing as needed
- Support mission operations with near real-time data analysis
- Analyze data as available to provide a gauged mass output for O2 and CH4 tanks
- Document results in RFMG-IM Final Report

CHALLENGES/RISKS TO THE PROJECT

- IM's Flight tank assembly, integration, and test schedule may impact remaining milestones
 - Recent cryo proof test identified issues being worked by IM on forward path
- Pre-flight RF Simulations
 - Temporarily on hold while IM works to identify forward path
 - Will continue pre-flight 1-g and micro-g RF simulations in coming weeks/month
 - Fluid simulations build on 1-g and micro-g ullage locations
- High-Power Computing Cluster coordination
 - Simulations are computationally intense
 - Looking at additional nodes to maximize RF Simulation software license (upgrade from 20 to 32 nodes)

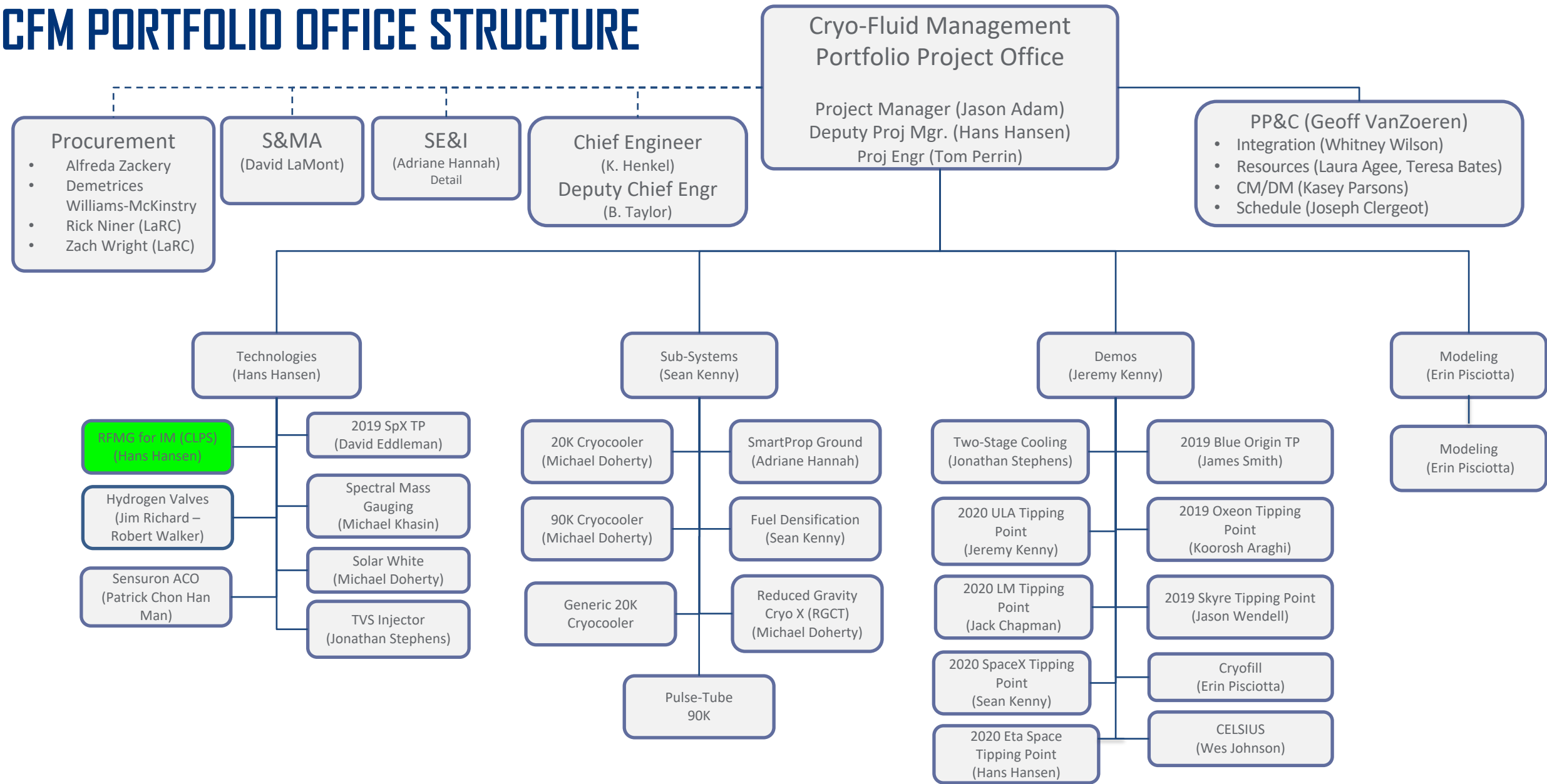
TRANSITION/INFUSION PLANS

- Pursuing reimbursable Space Act Agreement with IM to support RFMG integration on IM-2 mission
 - GRC provides RFMG SME support, install Software
 - IM contract to 3rd party to build-to-print the RFMG avionics
 - GRC transfers RFMG antenna/avionics design details to IM
- Further develop gauging software to Class D
 - Formal release of gauging algorithm software (restricted distribution, export controlled)
- Support US space industry partners through formal collaborations as requested
 - Work with GRC Tech Transfer Office to determine best path forward for tech transfer
 - Commercialization is complicated by export control of the technology and expired patent
- Develop ***NextGen RFMG*** – Considering Over-guide proposal in PPBE24 under CFM Portfolio Project
 - Further development of DARPA-funded prototype Class A/B RFMG controller
 - Explore Software Defined Radio approach for fast RF gauging
 - Explore Machine Learning and AI approach for matching data to simulation database
 - Employ and train young engineers on RFMG techniques

Continue to infuse RFMG with industry stakeholders building on successes from STMD investments!

Backup

CFM PORTFOLIO OFFICE STRUCTURE



RFMG-IM Summary Schedule (2021-2022)

